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EXCITATION OF HEXADECAPOLE TRANSITIONS IN ^{196}Pt VIA ELECTRON SCATTERING AND THEIR INTERPRETATION IN THE INTERACTING BOSON APPROXIMATION

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Form factors of transitions to three $I^\pi = 4^+$ states in ^{196}Pt, obtained from electron scattering, are analyzed in the framework of the interacting boson approximation. Structure functions differ strongly from liquid drop model predictions and provide an indication for the need of including the g-boson in IBA.

The interacting boson approximation (IBA) has been quite successful in describing level schemes and transition rates between collective states of even–even nuclei. Since the radial degree of freedom is absent in the model, only transition rates at the photon point ($q \to 0$) can be obtained. A natural and elegant way to extend the model to a treatment of finite momentum transfer has been proposed by Dieperink et al. [1]. The method consists of the introduction of an explicit dependence on radius in the structure functions of the transition operators. In IBA-1, where proton and neutron degrees of freedom are not dintinguished, the E2 and E4 operators are expressed as [2]

$$\hat{\rho}^{(2)}(r) = \alpha^{(2)}(r)(\mathrm{d}^\dagger \tilde{\mathrm{s}} + \mathrm{s}^\dagger \tilde{\mathrm{d}})^{(2)} + \beta^{(2)}(r)(\mathrm{d}^\dagger \times \tilde{\mathrm{d}})^{(2)} ,$$

$$\hat{\rho}^{(4)}(r) = \beta^{(4)}(r)(\mathrm{d}^\dagger \times \tilde{\mathrm{d}})^{(4)} . \qquad (1)$$

In the extension to IBA-2, proton and neutron bosons are treated as distinguishable entities and the operators are given for each multipolarity λ, in obvious notation, by

$$\hat{\rho}^{(\lambda)}(r) = \hat{\rho}_\pi^{(\lambda)}(r) + \hat{\rho}_\nu^{(\lambda)}(r) . \qquad (2)$$

From the form factors measured in electron scattering transition densities are obtained via a Fourier–Bessel analysis. These are linear combinations of the structure functions such as appear in eq. (1), their coefficients being the matrix elements of the boson operators. The latter can be calculated, once a parametrization of the hamiltonian has been adopted. The extent to which they can vary within the range of acceptance parametrizations is a topic that needs further investigation but falls outside the scope of this work. In the present work they are treated as known constants in the analysis. Thus, if one measures, for a given multipolarity, as many form factors of different transitions as there are structure functions, these functions may be determined separately. Cases where one observes a redundant number of transitions allow for a consistency check. Investigations along this line have so far been made only in an IBA-1 formulation for quadrupole transitions in the nuclei ^{150}Nd [1], ^{154}Gd [3] and ^{110}Pd [4]. It was found that the structure function $\alpha^{(2)}(r)$ has a surface peaked shape resembling the first derivative of a charge distribution, while $\beta^{(2)}(r)$ looks more like a second derivative. This is precisely the result that one obtains from the liquid drop model (LDM) with only quadrupole deformation [5], by identifying naively the d-boson with the quadrupole phonon and retaining only phonon-number conserving terms in a second

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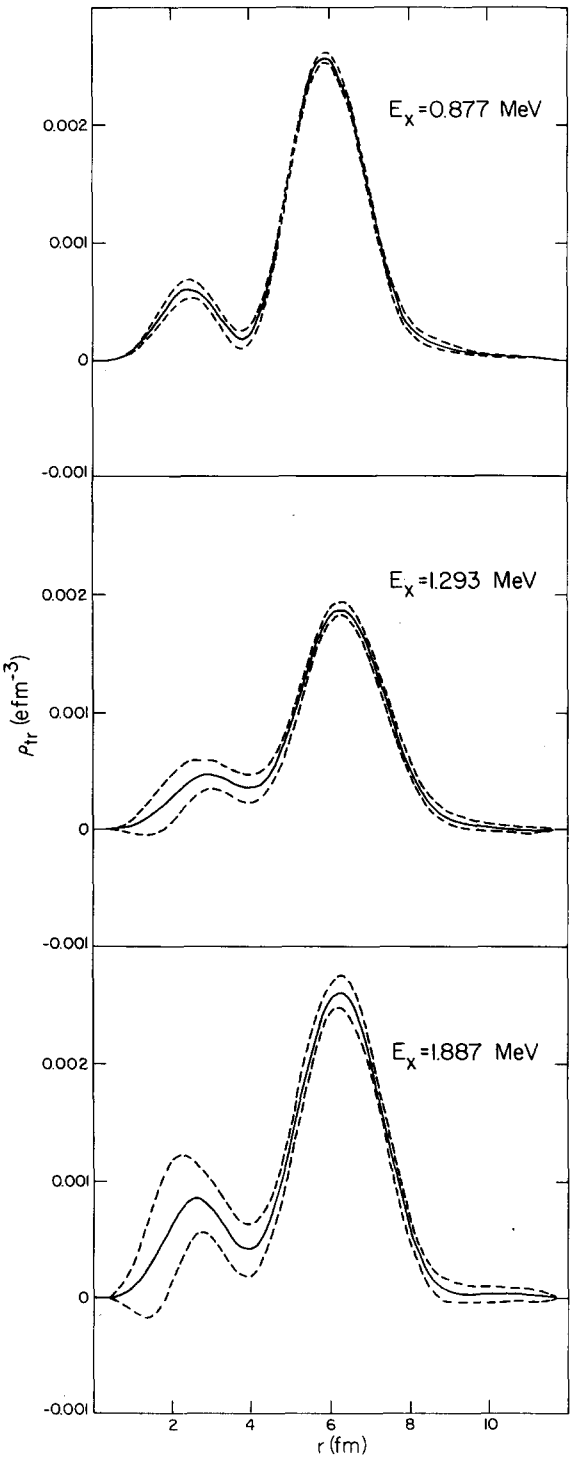

order Taylor expansion of the deformed density distribution. Upon the same grounds one expects also the structure function of the hexadecapole operator $[d^\dagger \times \tilde{d}]^{(4)}$ [eq. (1)] to be of the second derivative type. A dynamic hexadecapole deformation of the density distribution giving rise in the LDM to a first derivative shape would in the IBA find its analogon in the g-boson. Although an indication for g-bosons has been obtained from E4 strength distributions observed in inelastic proton scattering [6], the possibility to obtain transition densities from electron scattering may help to resolve the long standing debate on whether or not the g-boson is needed in IBA.

In this letter we present electron scattering data on ^{196}Pt, which nucleus has been proposed as a good example of the O(6) limit of IBA. Form factors of hexadecapole transitions are analyzed in the above described framework, considering both the IBA-1 and IBA-2 formulations.

Data were taken with the QDD spectrometer at NIKHEF-K at 31 angle–energy combinations, covering a range in momentum transfer of q_{eff} from 0.36 to 2.43 fm^{-1}. A selfsupporting ^{196}Pt target, with a thickness of 7.8 mg/cm^2 was used. The system was operated in the dispersion matching mode. A resolution of typically 7×10^{-5} was achieved. Details on the accelerator, the beam handling system and the spectrometer with its associated detector equipment are described in ref. [7]. We observe three $I^\pi = 4^+$ states, at E_x = 0.877, 1.293 and 1.887 MeV. The deduced transition densities of the three states are shown in fig. 1. From these the B(E4) values for the transitions to the states at E_x = 0.877, 1.293 and 1.887 MeV are determined to be 2.4(5), 2.0(4) and 4.4(1.3) in units of $10^6\ e^2\mathrm{fm}^8$, respectively. Deason et al. [8] have tentatively assigned $I^\pi = 4^+$ to states at E_x = 2.008 and 2.28 MeV. The peaks observed at these energies in our experiments are composite. On the basis of their form factors we cannot confirm or disconfirm the above assignment. Recently, Schüler et al. [9] have, via a (d, pnγ) study, observed a state at E_x = 1.537 MeV that might be interpreted as the 4_3^+ ($\tau = 4$) state of IBA-1. We did not identify this state in our experiment.

◀ Fig. 1. Experimental transition densities for the $I^\pi = 4^+$ states at E_x = 0.877, 1.293 and 1.887 MeV. The choice of the sign is arbitrary.

In IBA-1 the hexadecapole operator has only one structure function and is is predicted that in electron scattering only the 4_1^+ state is excited, while the strengths to all higher 4^+ state vanish. This observation is made for all parametrizations appropriate for the O(6) limit, like e.g. given by Casten et al. [10]. The fact that also the next higher 4^+ states, which are contained in the model, are found to be excited invalidates this description. Here, we investigate a description in IBA-2, where one has two structure functions. Such a parametrization of the platinum isotopes has been given by Bijker et al. [11]. Using their results one obtains the boson matrix elements, given in table 1. We determined the two structure functions from the transition densities of the states at $E_x = 0.877$ and 1.293 MeV which correspond to the 4_1^+ and 4_2^+ model states. The signs of these transition densities are unknown. There are therefore two solutions. The first, to which we shall refer as solution 1, corresponds to choosing the signs equal whereas the second solution (solution 2) arises for opposite signs. The structure functions found for both solutions are shown in fig. 2. For solution 1 they are very close in shape and magnitude but of opposite sign and both have a surface-peaked shape. The proton structure function peaks slightly more outward than that of the neutron. For the second solution the peak height of the proton function is about three times larger than that of the neutron function and also of opposite sign. The shapes are less similar here than for the first solution, but again both have a surface peaked shape.

The effective charges pertinent to the photon-point expression of the E4 operator are found from the relation

$$e^{(4)}_{\nu(\pi)}\beta^{(4)}_{\nu(\pi)} = \int \beta^{(4)}_{\nu(\pi)}(r)\, r^6\, \mathrm{d}r\,,$$

Table 1
The IBA-2 matrix elements for 4^+ states in ^{196}Pt, in the parametrization of ref. [11].

state	$\langle f \Vert [d^+ \times \tilde{d}]^{(4)}_\nu \Vert 0\rangle$	$\langle f \Vert [d^+ \times \tilde{d}]^{(4)}_\pi \Vert 0\rangle$
4_1^+	−0.8808	−0.6522
4_2^+	0.2364	0.4231
4_3^+	0.1076	−0.0176
4_4^+	−0.0542	0.2805

giving the result $e^{(4)}_\nu\beta^{(4)}_\nu = -0.243(18) \times 10^4$ fm^4 and $e^{(4)}_\pi\beta^{(4)}_\pi = 0.247(20) \times 10^4$ fm^4 for solution 1 and $e^{(4)}_\nu\beta^{(4)}_\nu = -0.040(18) \times 10^4$ fm^4 and $e^{(4)}_\pi\beta^{(4)}_\pi = 0.134(25) \times 10^4$ fm^4 for solution 2. These structure functions can then be used to calculate the form factors of the third and fourth model states. In fig. 3 these predictions are compared with the experimental form factor of the observed $I^\pi = 4^+$ state at $E_x = 1.887$ MeV. For the first solution the B(E4) values are predicted to be $0.84(13) \times 10^6$ and $6.10(10) \times 10^6\ e^2$ fm^8 for the 4_3^+ and 4_4^+ model states, respectively, and for the second solution the predicted values are $0.04(13) \times 10^6$ and $1.40(10) \times 10^6\ e^2$ fm^8. Qualitative agreement may be claimed only if the $E_x = 1.887$ state is identified with the 4_4^+ model state irrespective of which solution is adopted. It would mean that the third state has escaped idenfification because of its much smaller cross section. Success or failure of such interpretation hinges crucially on the existence or non-existence of a third $I^\pi = 4^+$ state around $E_x = 1.6$ MeV. In this light a confirmation or rejection of the tentative 4^+ assignment to the newly found state at $E_x = 1.537$ MeV by Schüler et al. [9] becomes urgent.

The transition densities of the three 4^+ states are all of the surface peaked type resembling a first derivative of the charge distribution. This is in sharp contrast with what would be expected from the liquid drop model with both static and dynamic deformation of quadrupole nature only. As an example we show in fig. 4 transition densities for transitions to the $I^\pi = 4^+$ states of the ground state-, beta- and gamma-bands calculated for a statically deformed mass distribution with $\beta = 0.12$, upon which dynamical quadrupole oscillations are superimposed. As pointed out above the transition densities arise from the second-order term in the Taylor expansion of the charge distribution, which leads to a second-derivative type of radial dependence. This was experimentally confirmed to be the case for quadrupole transitions in ^{150}Nd [1]. For hexadecapole transitions in vibrational nuclei in the Mo–Pd region, Cereda et al. [12] found that second derivatives reproduce proton scattering data better than first derivatives. On the other hand a dynamical hexadecapole deformation gives rise to a first-derivative type of transition density and in IBA this would be associated with a g-boson.

In summary, the observed transition densities for

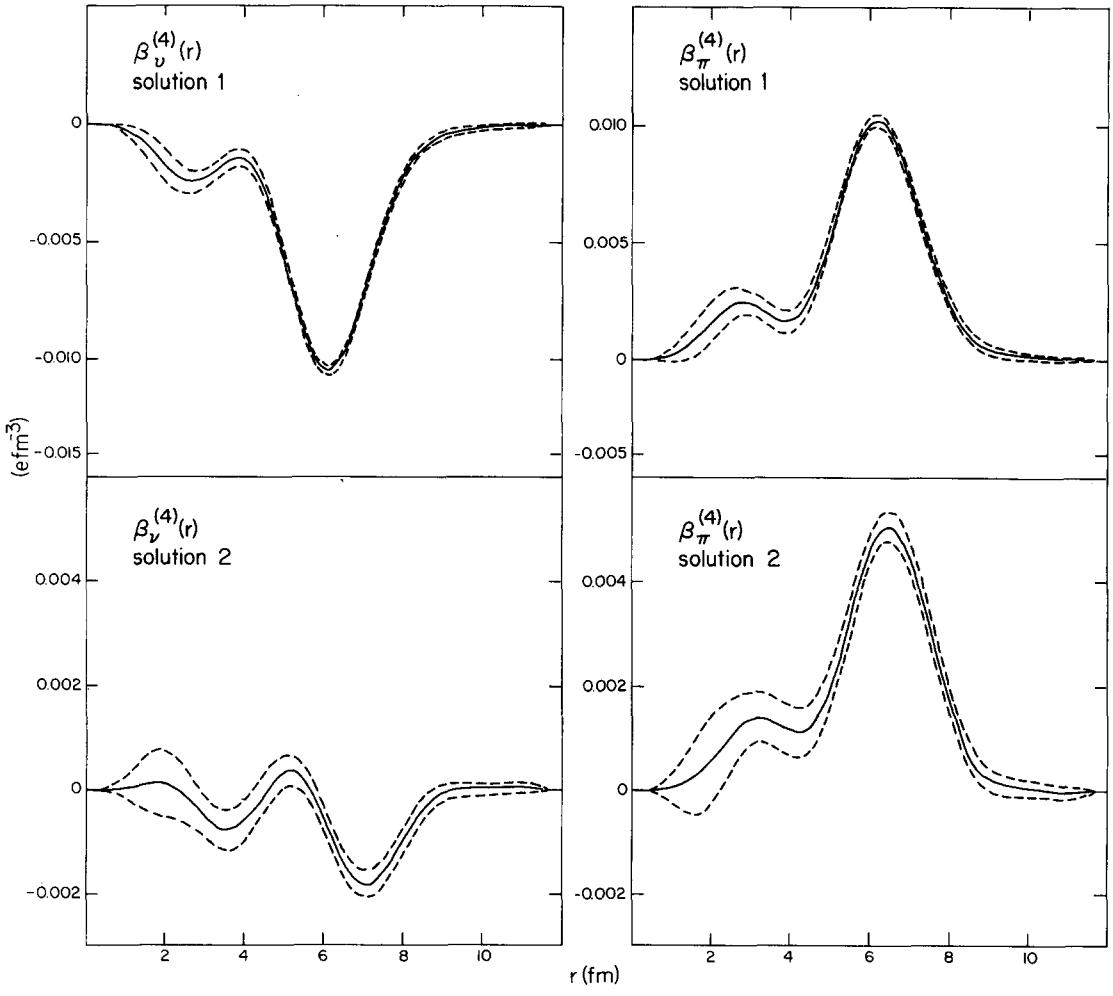

Fig. 2. Neutron and proton structure functions, derived from the transition densities of the E_X = 0.877 and 1.293 MeV states. Solutions 1 and 2 correspond to different relative signs of the transition densities to the two 4^+ states. See text for more details.

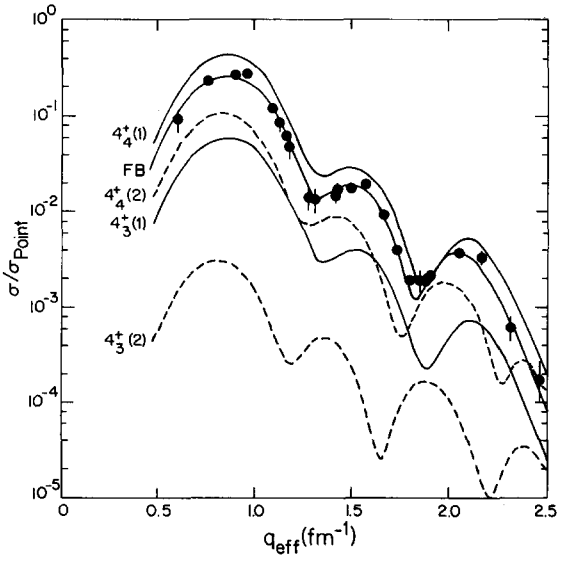

Fig. 3. The experimental form factor of the state at 1.887 MeV, compared with the calculations for the 4_3^+ and 4_4^+ model states of IBA-2. The corresponding solutions are indicated by (1) or (2). The solid curve through the data resulting from the Fourier–Bessel analysis is indicated by FB.

hexadecapole transitions in ^{196}Pt seem to indicate the need for the inclusion of a g-boson in IBA. This conclusion hinges on the extent to which the IBA multipole operator terms, quadratic in the d-boson, may be identified with those that in the LDM model are quadratic in the quadrupole phonon. This point needs further careful investigation. In spite of the similarity in the algebraic structure of the multipole operators the microscopic interpretations of the d-boson and the quadrupole phonon are quite different. The former describes a collective pair of particles (holes), while the latter is interpreted as a collective

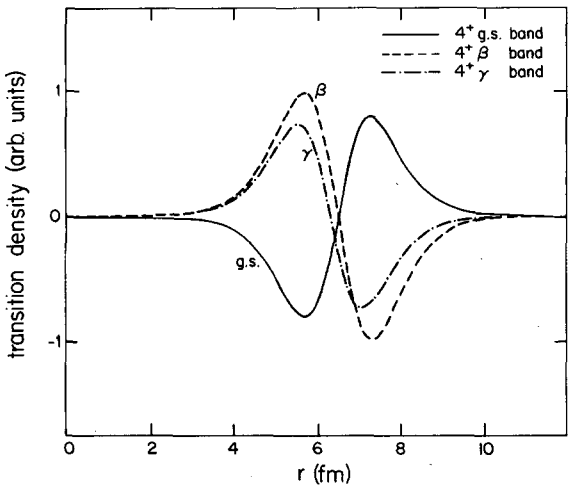

Fig. 4. Transition densities for the $I^{\pi} = 4^{+}$ members of the g.s.-, beta- and gamma-bands calculated from the liquid drop model, with static deformation parameter $\beta = 0.12$.

particle–hole excitation. It would be illuminating to start from a full shell model description, where the expressions for the multipole operators are known and study the effect on the transition densities of a truncation to $L = 0$ and 2 pairs. Conversely one could start from an IBA description and map back to the fermion space by employing the microscopic representations as given for example by Pittel et al. [13].

The proton- and neutron-structure functions, derived in this work are opposite in sign, suggesting that the hexadecapole operator would be purely isovector (solution 1) or at least predominantly isovector in character (solution 2). However, the 4^{+} states are excited by alpha scattering just as well [14] and the operator is rather expected to be purely isoscalar.

This observation implies that in IBA-2 with s- and d-bosons only, these bosons cannot be considered as pairs of *physical* protons or neutrons. This unsatisfactory situation again indicates the need for the introduction of a g-boson.

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